

# COMETARY DUST CHARACTERISTICS: COMPARISON OF STARDUST CRATERS WITH LABORATORY IMPACTS.

A. T. Kearsley<sup>1</sup>, M. J. Burchell<sup>2</sup>, G. A. Graham<sup>3</sup>, F. Hörz<sup>4</sup>, P. A. Wozniakiewicz<sup>1</sup> and M. J. Cole<sup>2</sup>. <sup>1</sup>Department of Mineralogy, The Natural History Museum, London, SW7 5BD, UK, ([antk@nhm.ac.uk](mailto:antk@nhm.ac.uk)), <sup>2</sup>Centre for Astrophysics and Planetary Sciences, School of Physical Science, University of Kent, Canterbury, CT2 7NR, UK, <sup>3</sup>Institute of Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550-9234, USA, <sup>4</sup>NASA Johnson Space Centre, Houston, Texas, USA.

**Introduction:** Aluminium foils exposed to impact during the passage of the Stardust spacecraft through the coma of comet Wild 2 have preserved a record of a wide range of dust particle sizes [1]. The encounter velocity and dust incidence direction are well constrained [2] and can be simulated by laboratory shots. A crater size calibration programme based upon buckshot firings of tightly constrained sizes (monodisperse) of glass, polymer and metal beads has yielded a suite of scaling factors for interpretation of the original impacting grain dimensions [3]. We have now extended our study to include recognition of particle density for better matching of crater to impactor diameter. A novel application of stereometric crater shape measurement, using paired scanning electron microscope (SEM) images has shown that impactors of differing density yield different crater depth/diameter ratios [4]. Comparison of the three-dimensional gross morphology of our experimental craters with those from Stardust reveals that most of the larger Stardust impacts were produced by grains of low internal porosity.

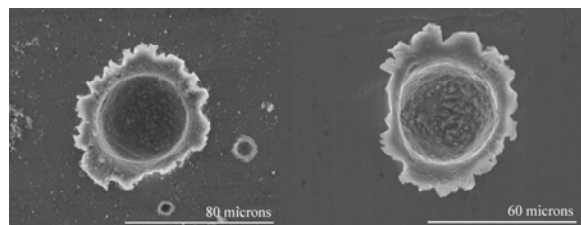


Figure 1. Left, an impact crater from a laboratory light gas gun shot of olivine onto Stardust foil. Right, a 'large' impact crater on Stardust foil C2086N,1.

**Experimental Analogues:** We used targets from Stardust flight spare Al 1100 foil. Buckshot was fired with the two-stage light gas gun (LGG) at the University of Kent [5] using polydisperse projectiles of olivine ( $3.4 \text{ g cm}^{-3}$ ), diopside ( $3.2 \text{ g cm}^{-3}$ ), bytownite feldspar ( $2.7 \text{ g cm}^{-3}$ ) and pyrrhotite ( $4.7 \text{ g cm}^{-3}$ ) as well as the same monodisperse soda lime glass ( $2.4 \text{ g cm}^{-3}$ ), polymethyl methacrylate (PMMA,  $1.19 \text{ g cm}^{-3}$ ) and steel ( $7.9 \text{ g cm}^{-3}$ ) samples as [3].

**Instrumental Methods:** Backscattered electron (BEI) and secondary electron images (SEI) were acquired on a JEOL 5900LV scanning electron micro-

scope with an Oxford Instruments INCA energy dispersive X-ray detector at the Natural History Museum, London. For each crater, a pair of images were taken, separated by  $6^\circ$  of specimen tilt ( $3^\circ$  to each side of beam-normal incidence). Images were processed using Alicona MeX® software, and digital elevation models were generated from which a colour-coded depth model and vertical crater cross sections were extracted. The plan view of the depth model clearly reveals the surface outline shape, any deviation from radial symmetry, and the location of the deepest point. Maximum crater depth ( $D_e$ ) below the original foil surface (ambient plane) and internal crater diameter ( $D_i$ ) on ambient plane can be measured easily from the section.

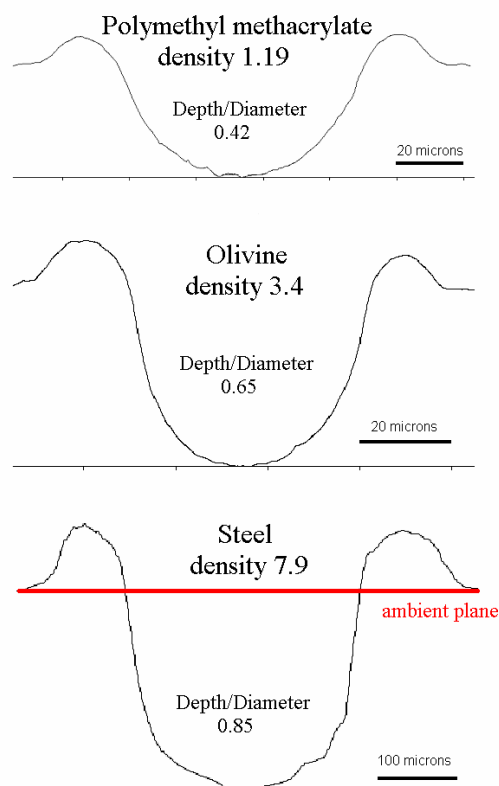


Figure 2. Examples of depth profiles from MeX digital elevation models of laboratory impacts onto Al 1100 alloy by projectiles with differing density.

**Results:** Almost all the experimental craters produced by our solid, low-porosity projectiles have a simple bowl-shaped morphology, with strong radial symmetry. Their depth to diameter (De:Di) ratio varies with density from 0.42 (PMMA) to 0.85 (steel); silicate and sulfide grains giving craters of De:Di typically between 0.54 and 0.65. Seven large Stardust craters (>50 microns diameter) were measured [1], and their residue contents analysed [6,7]. Stereo pair electron images were processed using MeX. Depth models and vertical sections of six circular craters showed that five are simple single 'bowl' shapes (e.g. Fig. 3, top) with De:Di between 0.56 and 0.77. The largest crater (C2086N,1) was deformed by detachment from the underlying frame to which it had been impact-welded. This crater was probably formed by a grain exceeding 40 microns in diameter and > 170ng mass, and containing at least one presolar grain [8]. Another apparently circular feature (on foil C2091N,1) has a more complex vertical profile, with an irregular, flatter floor and a double lip. The seventh feature (foil C2029W,1) is very complex; depth profiles reveal at least 12 overlapped partial bowl shapes in a patch of >140 microns diameter (Fig. 3, lower). De:Di is 0.24, but the structure is really a field of many superimposed craters.

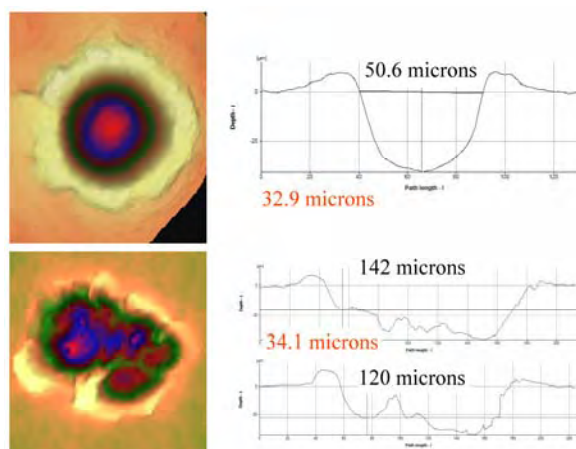


Figure 3. Color-coded depth models and vertical depth profiles of Stardust craters C2009N,1 and C2029W,1.

EDX spectra from all the large Stardust craters showed residue rich in Mg-silicates; in two circular craters substantial quantities of alkali-rich silicate were also found, and small quantities of Fe sulfides in three craters. In situ quantitative EDX analyses using tilted geometry [4] gave atomic ratios consistent with olivine in 3 craters, with a range of Forsterite:Fayalite from 97.5:2.5 to c.a. 65:35, and containing variable Cr contents in the more Mg-rich examples. These determinations are similar to the Stardust aerogel terminal parti-

cles [6]. Component sub-depressions of the complex crater cluster on foil C2029W,1 contain a diverse range of residues (Fig.4), probably from Mg-rich olivine, Mg-rich pyroxene, Ca clinopyroxene, Fe and FeNi sulfides, alkali-rich glass and possible organic material. Bulk composition of this assemblage is close to the major element ratios seen in CI chondrites.

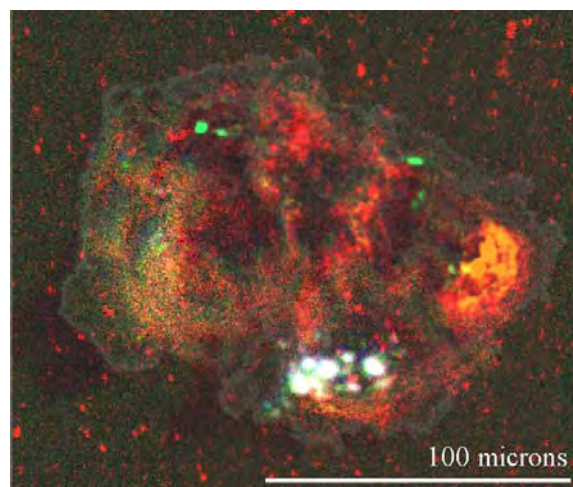


Figure 4. X-ray maps of the complex crater group on foil C2029W,1. Mg green; Al grey; Si blue; S yellow; Ca white; Fe red. Note Fe-rich inclusions in alloy.

**Conclusions:** Density-corrected particle size and mass calibration [4] can be applied to five large simple 'bowl'-shaped Stardust craters examined during the preliminary evaluation, as their depth profiles suggest their impactor density was similar to the low-porosity silicates ( $2.6$  to  $3.4 \text{ g cm}^{-3}$ ) used in our experiments. The complex crater cluster on foil C2029W,1 reflects impact by a large grain with low density and high internal porosity, a loosely bound aggregate of smaller particles, ca. 100 microns across.

**References:** [1] Hörz F. et al. (2006) *Science*, 314, 1716-1719. [2] Brownlee D.E. et al. (2003) *JGR*, 108(E10): 8111, 10.1029/2003JE002087. [3] Kearsley et al. (2006) *MAPS*, 41.2, 167-180. [4] Kearsley A.T. et al. (2007) *MAPS*, 42.2, in press. [5] Burchell M.J. et al. (1999) *Meas. Sci. Tech.* 10, 41-50. [6] Zolensky M.E. et al. (2006) *Science*, 314, 1735-1739. [7] Flynn G. et al. (2006) *Science*, 314, 1731-1735. [8] McKeegan K. et al. (2006) *Science*, 314, 1724-1728.

**Acknowledgements:** We thank NASA for the Stardust foil used as targets in the light gas gun shots and PPARC for support of the gun facility at Canterbury. Giles Graham acknowledges his work was performed under the auspices of the US Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.